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Performance of a new-type integrated biofilm reactor in treating high concentration organic wastewater

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Abstract

A new-type integrated anaerobic-aerobic biofilm reactor (IAOBR) was designed to treat high concentration organic synthetic wastewater. The IAOBR comprised of an anaerobic fluidized bed reactor and an aerobic one. The IAOBR experienced 38 days of startup with increasing organic load rates (OLRs) gradually, and could achieve COD removal efficiency of 84.4-96.1% and NH3-N removal efficiency as high as 91.7% during the operation phase. In that case, COD and NH3-N concentrations in the influent were 2761-4653 mg/L and 280.3-350.7 mg/L, respectively. The IAOBR exhibited excellent resistance to COD load shock. However, the increase of C/N ratio from 10.5 to 12.1 caused negative effect on nitrification. On the whole, the new-type IAOBR exhibited good potential for treating organic wastewater containing high COD and moderate NH3-N concentrations.

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Keywords: Integrated anaerobic-aerobic biofilm reactor; Biological fluidized bed; COD; NH3-N

1. Introduction

Developing cost-effective biological reactors is always an important issue in the field of wastewater treatment. Biofilm reactors instead of traditional activated sludge tanks have gained more and more attention of many researchers. As one of biofilm reactors, biological fluidized bed reactors (BFBRs) feature a high biomass concentration, a high mass transfer efficiency, a high buffer capacity, a high loading rate, and less ground area demand, etc.[1,2]. However, the applications of BFBRs were ever limited by the lack of lightweight, easy fluidizable, inexpensive and durable carriers. Fortunately, the limitation has been overcome in recent twenty years by the flourish of new-type carriers, such as diatomaceous earth-based Celite R-633[3] and wire mesh sponge particles[4].

In real-world applications, anaerobic BFBRs and aerobic BFBRs were always separately constructed, which was not desirable in saving ground area and energy. In this study, an anaerobic BFBR and an aerobic BFBR were integrated, and a new-type integrated anaerobic-aerobic biofilm reactor (IAOBR) was

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designed. Compared with separate applications, this IAOBR had advantages such as less installation, less construction investment, less operation cost, and less ground area, etc..

The main objective of this study is to investigate COD and NH_3-N removal performance of this new-type IAOBR in treating synthetic wastewater containing high COD and moderate NH_3-N concentrations.

2. Materials and methods

2.1 IAOBR setup

As shown in Figure 1, the bench-scale new-type IAOBR is mainly consisted of three coaxial plexiglas cylinders. The inner cylinder is used as an anaerobic BFBR with working volume of 8.6 L. An annular perforated pipe is set for distributing wastewater at the bottom and a three-phase separator is set at the top of the inner cylinder. The middle and outer cylinders are used as an aerobic BFBR with working volume of 40 L. A circulation tube is set outside the outer cylinder. The aeration system is comprised of an air compressor (ACO-008A, Risheng Group, Guangdong, China), a gas flow meter (LZB-6, Zhenxing Flow Instrument Factory, Jiangsu, China) and a micropore aeration loop. The loop is located between the middle and the outer cylinders. The aeration strength is controlled by a gas flow meter.

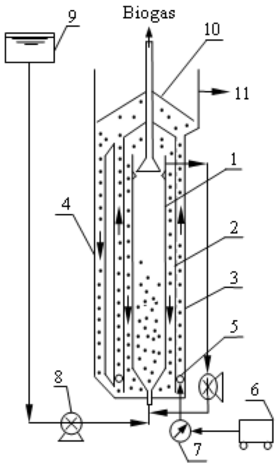

Figure 1 Schematic diagram of the new-type IAOBR.
1, Inner cylinder; 2, Middle cylinder; 3, Outer cylinder; 4, Aerobic recirculation tube; 5, Micropore aeration loop; 6, Air compressor; 7, Gas flow meter; 8, Peristaltic pump; 9, High feed tank; 10, Arc baffle; 11, Discharge.

Synthetic wastewater is poured into a high feed tank and then pumped into the inner cylinder by a peristaltic pump. The wastewater flow upward in the inner cylinder and is divided into two splits. One split is pumped back to the bottom of the inner cylinder, which forms a circulation; the other split flow downward into the middle cylinders due to gravity and subsequently flow upward in the outer cylinder due to aeration. When wastewater flows into the upper zone of the IAOR where sedimentation takes place, it divides into two splits again. One split flows downward to the bottom of the outer cylinder through a recirculation tube due to gravity; the other split is discharged. An arc baffle set in the upper zone is beneficial to sedimentation.

2.2 Carriers [5]

Porous polymers were used as carriers in this study. The polymers have a geometric mean diameter of 0.32 mm, a true density of 1320 kg/m^3, a wet stacking density of 1010 kg/m^3, a pore volume of 0.301 mL/g, and a wet specific surface area of 5357 m^2/m^3.

2.3 Synthetic wastewater

The basic composition of synthetic wastewater is: glucose, 3000 mg/L; NH_4Cl, 1000 mg/L; $NaHCO_3$, 2500 mg/L; $MgSO_4 \cdot 7H_2O$, 1500 mg/L; $KHPO_4$, 200 mg/L; KH_2PO_4, 200 mg/L. The composition was adjusted to get various concentrations of synthetic wastewater. Besides above agents, some micronutrient and trace metal agents, including $CoCl_2 \cdot 6H_2O$, $NiCl_2 \cdot 6H_2O$, $MnCl_2 \cdot 6H_2O$ and $ZnCl_2$, are added into synthetic wastewater.

2.4 Seeding sludge

Anaerobic seeding sludge was collected from an up-flow anaerobic sludge blanket (UASB). Aerobic seeding sludge was collected from a secondary sedimentation tank in a municipal wastewater treatment plant.

2.5 Analytical methods

Chemical oxygen demand (COD) and ammonia (NH_3-N) were measured using Standard Methods (APHA, 1998). Dissolved oxygen (DO) was continuously monitored by WTW, pH/oxi340i meter with DO probes (WTW Company, Germany). Temperature and pH were detected on line using WTW level 2 pH meters (WTW Company, Germany). Bio-particle samples were subjected to a scanning electron microscopy (SEM, Hitachi S-520, Japan).

2.6 Reactor startup and operation

The whole experiment can be divided into two phases, i.e., the startup and operation phase. During the startup phase, the anaerobic BFBR and aerobic BRBR started up in turn, with increasing organic load rates (OLRs) gradually. In 38 days, the COD removal rates could be steadily maintained at 80% or higher for IAOBR, demonstrating the success of startup. During the operation phase, OLRs were increased gradually. During the entire experiment, temperature was not exclusively controlled. The room temperature was 16-25 ℃ and 25-30 ℃ during the startup and operation phase, respectively. The concentration of DO in the aerobic BFBR was maintained at 6.0 mg/L. The pH value in the feed was controlled around 7.0. The recirculation ratio of the anaerobic BFBR was controlled at a level of 3-4.

3. Results and discussion

3.1 COD removal efficiency during operation phase

The operation phase lasted 58 days. The concentrations and removal rates of COD were presented in Figures 2-3. As shown in Figure 2, when COD concentrations in the influent ranged from 2761.0 to 4653.0 mg/L, the COD concentrations were 991.2-2626.7 mg/L after anaerobic treatment and 148.7~746.7 mg/L after aerobic treatment, respectively. Along with increase of COD concentrations in the influent, COD concentrations in the anaerobic effluent also increased, at a considerably low rate. However, COD concentrations in the aerobic effluent kept at a stable level of less than 500 mg/L. As shown in Figure 3, during the entire operation phase, COD removal rates of anaerobic BFBR, aerobic BFBR and IAOBR were 39.5-64.9%, 50.0-89.7%, and 84.4-96.1%, respectively. Obvious fluctuations appeared in the COD removal rate profile of anaerobic BFBR, indicating that resistance of anaerobic BFBR to COD load shock was not good enough. It should be noted that prior to the operation phase, IAOBR lasted only 38 days during the startup phase. Though COD removal efficiency could be steadily maintained at 80% or higher for IAOBR in 38 days, the majority of COD removal should be contributed to aerobic BFBR, instead of anaerobic BFBR. As we know, startup of an anaerobic process need a long time due to the slow growth of bacteria, especially methanogenic bacteria (MPB). Anaerobic biofilm may have not developed well to accommodate variations of OLRs during the operation phase. Different from the anaerobic BFBR, the aerobic BFBR achieved fairly stable COD removal efficiency. Along with the increase of COD concentrations in the influent, COD removal efficiency of the aerobic BFBR increased gradually and stabilized around 80%, demonstrating excellent resistance of aerobic BFBR to COD load shock. As a whole, COD removal rates of IAOBR were very stable. Most of the time, they were over 85%.

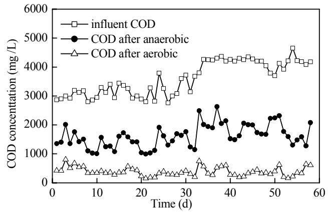

Figure 2 Concentration profiles of COD during the operation phase

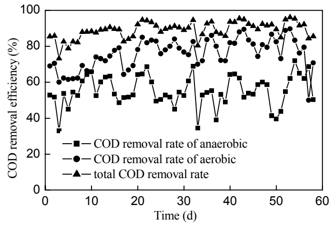

Figure 3 Removal efficiency profiles of COD during the operation phase

Table 1 NH3-N removal during the operation phase

NH_3-$N_{influent}$ (mg/L)	**$COD_{influent}$ (mg/L)**	**NH_3-$N_{effluent}$ (mg/L)**	**NH_3-N load rate ($kg/m^3 \cdot d^{-1}$)**	**NH_3-N removal efficiency (%)**
319.6	2761	100.8	0.21	68.5
304.7	3003	89.2	0.19	70.7
335.2	3084	63.7	0.22	81.0
341.9	3602	74.5	0.21	78.2
299.4	3142	24.8	0.18	91.7
300.8	3687	44.4	0.19	85.2
320.6	3805	56.8	0.19	82.3
350.7	4258	97.6	0.20	72.2

3.2 NH3-N removal efficiency during operation phase

The concentrations and removal efficiency of NH_3-N were presented in Table 1.

As shown in Table 2, when NH_3-N concentration in the influent were 280.3-350.7 mg/L and NH_3-N load rates of IAOBR were 0.17~0.23 kgNH_3-N/$m^3 \cdot d^{-1}$, NH_3-N concentrations in the effluent were 24.8-100.8 mg/L and NH_3-N removal rates were 68.5-91.7%. In the meanwhile, COD concentrations in the effluent were 2761-4258 mg/L and C/N ratios were 8.6-12.2.

Relatively high NH_3-N removal efficiency could be explained as follows: Firstly, NH_3-N concentrations in the influent were moderate and so were NH_3-N load rates; Secondly, DO concentration in aerobic BRBR was controlled at a relatively high level (around 6.0 mg/L). High DO concentration helped reduce the competition for oxygen between the nitrifying bacteria and heterotrophs and enhance nitrification of NH_3-N. Thirdly, the carriers used in this experiment were porous polymers, which are suitable for the immobilization of nitrifying bacteria. However, an obvious drop of NH_3-N removal efficiency (from 91.7 to 72.2%) happened when COD and NH_3-N concentrations in the influent were increased from 3142 to 4258 mg COD /L and 299.4 to 350.7 mgNH_3-N/L, respectively. During this course, C/N ratio was increased from 10.5 to 12.1. Nitrification efficiency was negatively affected by the increase in the C/N ratio has also been confirmed by several studies[6-8]. It implied that extra adjustments should be adopted to control nitrification when fed with wastewater of a high C/N ratio. For example, HRT was recommended in [9].

3.3 Microbial community

In order to preliminarily understand the microbial community in the IAOBR, bio-particles were sampled for SEM from the anaerobic and aerobic BFBR at 50^{th} days of the operation phase, respectively. Judged from the morphological characteristics, *Methanothrix soehngenii* and *Methanosarcina* are the main bacteria colonies immobilized on the surface and in the inner pores of the bio-particles sampled from the anaerobic BFBR, respectivly. While in the biofilm of bio-particles sampled from the aerobic BFBR, short bacilli and cocci are the main bacteria colonies in the inner pore and on the surface of bio-particles, respectively. Further molecular biologic approaches are needed to define the species of bacteria mentioned above.

4. Conclusions

A new-type IAOBR was designed to treat high concentration organic synthetic wastewater, achieving good COD removal efficiency (84.4-96.1%) during the operation phase and exhibiting excellent resistance to COD load shock. NH_3-N removal efficiency as high as 91.7% was achieved at a load rate of 0.18 kgNH_3-N/$m^3 \cdot d^{-1}$. The increase of C/N ratio had negative effect on nitrification. On the whole, the integration of an anaerobic and an aerobic BFBR could save ground area and costs (capital and operation) in real-world applications, and have good application prospect in treating organic wastewater containing high COD and moderate NH_3-N concentrations.

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